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Contestation, contingency, and justice in the Nordic low-carbon energy transition

Benjamin K. Sovacool[a,b,*]

[a] Department of Business Development and Technology, Aarhus University, Denmark
[b] Science Policy Research Unit (SPRU), School of Business, Management, and Economics, University of Sussex, United Kingdom

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ABSTRACT

The five Nordic countries have aggressive climate and energy policies in place and have already emerged to be leaders in renewable energy and energy efficiency. Denmark is renowned for its pioneering use of wind energy, Finland and Sweden bioenergy, Norway hydroelectricity and Iceland geothermal energy. All countries aim to be virtually "fossil free" by 2050. This study explores the Nordic energy transition through the lens of three interconnected research questions: How are they doing it? What challenges exist? And what broader lessons result for energy policy? The study firstly investigates the pathways necessary for these five countries to achieve their low-carbon goals. It argues that a concerted effort must be made to (1) promote decentralized and renewable forms of electricity supply; (2) shift to more sustainable forms of transport; (3) further improve the energy efficiency of residential and commercial buildings; and (4) adopt carbon capture and storage technologies for industry. However, the section that follows emphasizes some of the empirical barriers the Nordic transition must confront, namely political contestation, technological contingency, and social justice and recognition concerns. The study concludes with implications for what such historical progress, and future transition pathways, mean for both energy researchers and energy planners.

1. Introduction

This article explores the history and dynamics of the Nordic low-carbon energy transition. The Nordic region offers a paradigmatic example in the real world where communities, companies, and countries have taken concrete efforts to successfully reduce their greenhouse gas emissions and improve energy security. It has long been promoted within the academic literature as a blueprint for technological innovation and renewable energy deployment (Sovacool et al., 2008; Borup et al., 2008; Sovacool, 2013) as well as the underlying politics and institutional dynamics behind its energy and climate policies (Westholm and Lindahl, 2012; Nilsson et al., 2011) and its promotion of electricity trade and interconnection (Unger and Ekvall, 2003).

Today, the five countries that comprise the Nordic region—Denmark, Finland, Iceland, Norway, and Sweden—have progressive energy and climate policies that are perhaps the most ambitious in the world. Each has a series of longstanding policy goals; each has binding climate targets; each are attempting to become entirely or mostly "fossil fuel free" or "carbon neutral," with Denmark, Sweden, and Norway committed to 100% renewable energy penetration, Finland 80%, and Iceland 50–75%. Indeed, as the International Energy Agency and Nordic Energy Research (2016) recently noted, electricity generation across the Nordic region is already 87% "carbon-free" and the regional economy has "exhibited a steady decoupling of GDP from energy-related CO2 emissions and declining CO2 intensity in energy supply for decades."

This study explores the Nordic energy transition through the lens of three interconnected research questions: How are they doing it? What challenges exist? And what broader lessons emerge for energy policy? In answering them, the study aims to make three contributions. First, the Nordic experience may indeed offer lessons or a roadmap that other countries can follow. Important factors critical to successful Nordic decarbonization so far include an emphasis on industrial energy efficiency; a shift from fossil fuels to low-carbon forms of heating; expansion of distributed and renewable sources of electricity; and, perhaps most critically, a stable and supportive policy environment involving ambitious carbon taxes and strong incentives coupled with the almost complete displacement of fossil fuel and a moderation of nuclear power (which may not be going away so quickly). Contrary to much conventional wisdom, the Nordic energy transition illustrates that an energy system potentially based on distributed resources,

* Correspondence to: Business and Social Sciences and Center for Energy Technologies, Aarhus University, Birk Centerpark 15, DK-7400 Herning, Denmark.
E-mail address: BenjaminSo@hih.au.dk.

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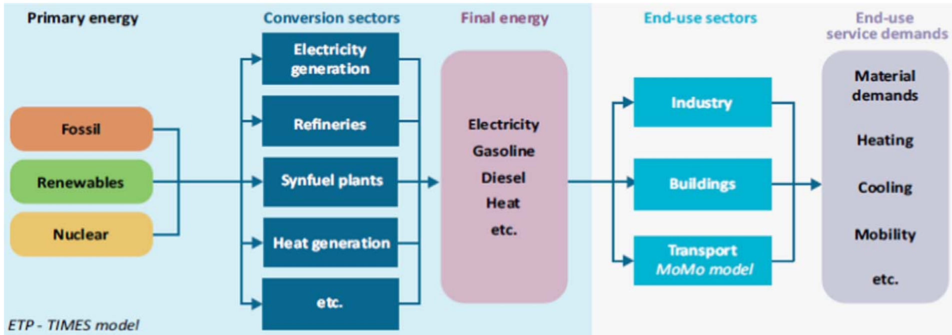


Fig. 1. Structure of the Nordic Energy Technology Perspectives model.
Source: Modified from International Energy Agency and Nordic Energy Research (2016), Nordic Energy Technology Perspectives 2016 (Paris: OECD, 2016). Notes: TIMES=The Integrated MARKAL-EFOM System, MoMo=Mobility Model.

interconnected European grids, and flexibility could be less costly, and deliver greater value through co-benefits, than one reliant entirely on centralized, fossil-fueled sources of energy. These technology and policy lessons could be worth exporting.

The second contribution of the article, however, is to emphasize the contingency and sheer difficulty of low-carbon energy transitions. Even if it all goes to plan—and it may not—the Nordic transition will still take decades until 2050. The Nordic countries must address the need to decarbonize transport as well as power and heat; build interconnectors to incentivize new power capacity; and green both residential buildings as well as large energy and carbon intensive industrial firms. The Nordic region also involves a set of countries that are relatively small in terms of geographic area and population, wealthy in terms of economic development, and socially committed to environmental goals. The Nordic countries sit on clean energy resources that could be exploited beyond the population's needs but suffer from varying degrees of social opposition in some circumstances. The region also remains a large net exporter of oil and gas. The transition, therefore, is contested and contingent, and it will create its own set of winners and losers. While the topic of transitions has become more prominent in the energy studies literature, most work has focused on other areas. Recent dimensions explored include the temporal dynamics or speed at which a transition can take place (Sovacool, 2016) as well as historical trends (Grubler et al., 2016; Smil, 2016; Fouquet, 2016a, 2016b), politics and governance (Kern and Rogge, 2016), and even cost and sectoral dimensions (Sovacool and Geels, 2016). But none have yet looked at how contingency, contestation, and justice can affect decarbonization pathways and create a series of obdurate challenges that can overcome even the best of intentions.

A third and final contribution is both future-orientated and practical. Although it has certainly been ongoing for at least a few decades now, the Nordic energy transition has not yet been completed. Because the Nordic countries have climate and energy targets that span into 2030, 2045, 2050 and beyond, they can still be influenced by stakeholders. This study therefore hopes to both exert influence over Nordic policy as well as temper the optimism inherent in the discourse about the future Nordic energy transition. It does this by underscoring the immensity of the task and raising the salience of perhaps neglected concerns surrounding technology, politics, and social justice. Ultimately, even if the Nordic region has perhaps the most progressive *policies*, it must match these over the coming decades with consistent empirical *performance*.

2. Research methods

The research design and primary data for this study draw heavily from International Energy Agency and Nordic Energy Research (2013) as well as International Energy Agency and Nordic Energy Research (2016). These two reports, both focused on energy and carbon technology pathways in the Nordic region, rely on a broader methodology employed in the International Energy Agency's *Energy Technology Perspectives*. This methodology involves a mix of back-casting and forecasting over different scenarios from the current time (2011 for the first report, 2013 for the second) to 2050. The approach attempts to reveal, through optimization modeling, the most economical ways for the Nordic societies to reach their desired outcome of being fossil-free by 2050. The idea is that by synthesizing different modeling approaches that reflect in-depth insights spread across different sectors, such as electricity or transport, one can get robust and reliable results. The section of the paper "How are they doing it" replicates the scenarios presented by this model, drawn from a mix of publicly available data connected to the two reports as well as enhanced and deepened analysis gleaned from correspondence with two of the report's authors, Benjamin Donald Smith and Markus Wråke.

More specifically, the "Nordic Energy Technology Perspectives" model, or NETP, allows for the integration of data from four sub-models: energy conversion, industry, transport, and buildings (meant to encompass residential and commercial entities). The NETP enables one to explore outcomes and scenarios matched to variables in energy supply (such as the intermittency of some renewable sources of electricity) as well as the dynamics of demand across three sectors (industry, transport, buildings) which are also the largest source of Nordic greenhouse gas emissions. Fig. 1 displays the complex interaction of these various elements and how the NETP treats processes that convert primary energy to final energy utilized across demand-side sectors. As the IEA states, the NETP is a cost optimization-based model designed to enable "a technology-rich, bottom-up analysis" of the Nordic energy system.

While the NETP model is state-of-the-art and still used by the IEA, a few shortcomings exist. As the IEA and Nordic Energy Research (2016) acknowledge, "many subtleties cannot be captured in a cost optimization framework: political preferences, feasible ramp-up rates, capital constraints and public acceptance." So, the model is best considered a useful snapshot or tool, rather than a completely accurate portrayal of reality. In other words, the long-term projections drawn from the NETP contain substantial uncertainties, and many of the assumptions underlying the analysis will change in the future, affecting its accuracy. Moreover, the NETP does not account for some of the secondary costs from climate change, such as investments made in adaptation and resilience. Lastly, although the NETP does account for innovation, technological learning, and reductions in cost among many energy systems, it relies heavily on the state of that technology (and its respective markets) as of 2016. Put another way, the NETP does not presume the appearance of sudden breakthrough technologies, nor does it rely on systems that were not considered commercially available as of 2016. That makes it well suited to study incremental changes, but transformative shifts are harder to fully capture. That said, the NETP does acknowledge Nordic energy and climate policies already imple-

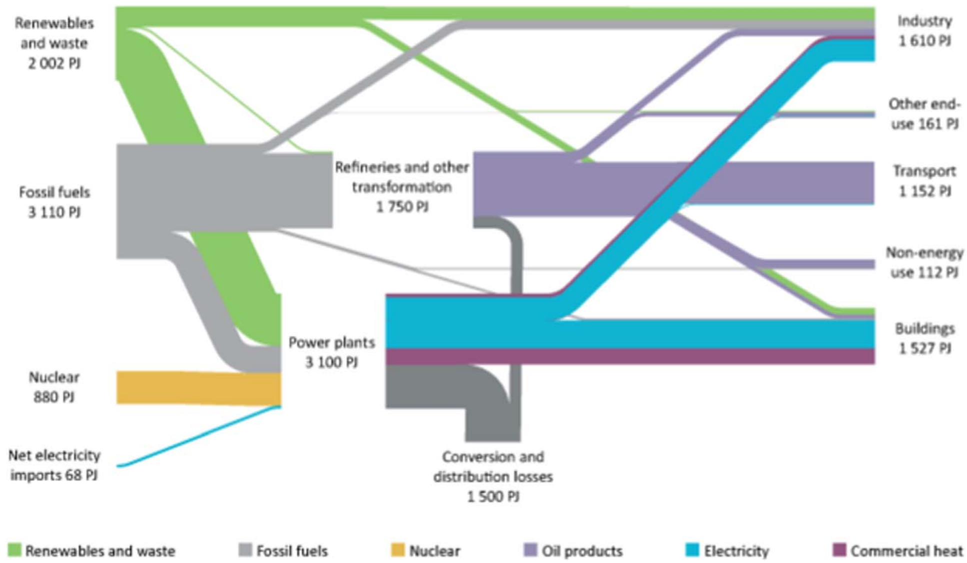


Fig. 2. Nordic Energy Flows by Sources, Pathways, and End-Use Sectors, 2013.Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2016) (Paris: OECD, 2016).

mented or committed—unlike other forecasts from groups like the U.S. Energy Information Administration which try to be "policy neutral" (Gilbert and Sovacool, 2016). Additionally, the model does reflect the complexity of integration, noting that as the Nordic region gets closer to 2050, the energy system comes to rely on a more diffuse portfolio of distributed technologies, which will typically depend on local conditions in a country and therefore require greater efforts of optimization.

The second half of the paper goes well beyond the analysis extracted from the NETP reports to assess likely sociotechnical barriers (Geels, 2004) organized around the themes of contingency, contestation, and energy justice. These themes, unique to this study, were compiled inductively and qualitatively from a search of both the recent peer-reviewed literature on the topic and insights from popular media and press accounts (mostly articles from English language domestic newspapers across the five Nordic countries) published from 2012 to 2016.

With its basic approach, methodology, and limitations laid out, the rest of this study proceeds as follows. The section "How are they doing it" focuses on an overview of Nordic energy conversion and use as well as its four decarbonization pathways—renewables, efficiency, transport, and industry. The section "What challenges exist" discusses possible challenges that can complicate such pathways, namely technological contingency as well as political contestation and energy justice.

3. How are they doing it?: Nordic decarbonization pathways

The five Nordic countries of Denmark, Finland, Iceland, Norway, and Sweden are not uniform. Each of them continues to see different market features emerge. Denmark urgently needs new ways of increasing the flexibility of its energy system to accommodate the variability of wind energy. Finland has an energy economy dominated by biomass and forestry products, is a net importer, hosts heavy industry, and is building new nuclear power units. Iceland has a huge fishing fleet fueled by diesel and remote communities in the Faroe Islands and Greenland depend on diesel generators. Norway remains heavily invested in oil and domestic hydropower, but has trouble monetizing its hydro resources due to a cheap surplus. Sweden remains (at the moment) wedded to mostly large hydropower and nuclear sources of supply and is pushing ahead with potentially regressive national green certificates for renewables at odds to the cost-optimized approach suggested by NETP which recommends a carbon tax or trading scheme. All countries remain dominated by carbon-intensive modes of transport and are in great need of low-carbon mobility infrastructure, and all need carbon capture and storage at iron, steel, chemical, and cement industrial facilities.

Nonetheless, as a region these five countries share some interesting features. As Fig.2 indicates, despite longstanding climate goals, aggregated energy supply (in petajoules, including oil and gas resources that are exported) is still dominated by fossil fuels (3110 PJ), the bulk of which are refined for transport and other end-uses, followed by renewables and waste (2002 PJ). A second notable feature is an almost even split in demand, with industry (1610 PJ) slightly ahead of residential and commercial buildings (1527 PJ) and transport (1152 PJ), correcting the misnomer that the Nordic region no longer has a strong manufacturing base. A final illustrative trend is the conversion and efficiency losses of 1500 PJ (or 24.8% of 6060 PJ in total supply), implying that while efficient compared to many other regions of the world, there are still significant efficiency gains to be captured. Fig. 3 helps break down primary energy production by both country—showing how Norway far surpasses other countries on an aggregate basis—and fuel source—showing how natural gas and oil still provide about three-quarters of regional energy supply.

As the rest of this section of the study indicates, the four pillars of the Nordic energy transition involve renewable electricity and heat, energy efficiency, transport, and industry.

3.1. Renewable electricity and heat

At present, about 87% of electricity generation in Nordic countries is low-carbon, of which 63% comes entirely from renewable sources. That said, there is still room for considerable expansion, especially involving wind energy, biomass and waste, hydro, and geothermal.

Although wind energy already comprises a substantial role in Denmark's electricity portfolio, and it is expected to grow rapidly between 2016 and 2050, even in Denmark biomass and waste provide far more primary energy supply, although some of this heat is lost in transformation and distribution. This trend of bioenergy and waste dominating is the same with Finland (led by biomass and waste for all renewables) and Sweden (biomass and waste followed by hydropower). Norway is led almost entirely by hydropower; Iceland by geothermal, as Fig. 4 illustrates.

The bottom panel of Fig. 4 also illustrates the likely shifts that need to occur within the electricity sector if carbon targets are to be reached, namely, a dramatic reduction in supply from more than 6000 PJ to roughly 4500 PJ. Net electricity exports, bioenergy and waste, wind,

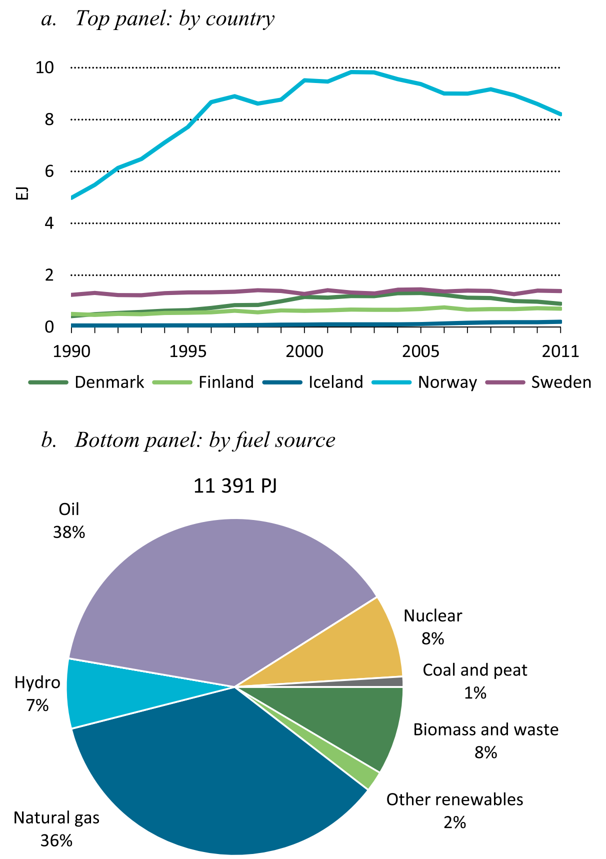


Fig. 3. Total Primary Energy Production in Nordic Countries, 1990–2011
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2013) (Paris: OECD, 2013). Note: EJ=Exajoules,

geothermal, solar, and hydroelectricity all expand significantly; coal, oil, natural gas, and nuclear power shrink. Indeed, bioenergy comes to surpass oil as the largest energy carrier, increasing to 1600 PJ, and also helping account for 40% of all emissions reductions (by displacing oil). Nordic hydropower expands, backed largely by the deployment of larger-scale, reservoir based installations supplemented with some "run of river" or microhydro units. Wind energy also rises to displace fossil and nuclear electricity generation. In fact, wind energy production increases so much—five-fold from 7% of Nordic generation to 30% by 2050—that its generation comes to far exceed domestic demand, even with the drop in nuclear power—this excess capacity starts to serve a lucrative export market in Europe. Much (70%) of this wind capacity is projected to occur in Denmark, and two-thirds of it is expected to be onshore, demonstrating the necessity of proper siting and public approval. Fig. 5 graphically depicts expected full load hours (wind quality) for both onshore and offshore configurations. The high penetration of wind power comes to be balanced and integrated through a mix of the aforementioned expansion of hydropower, flexible supply, demand response, some storage, and electricity trade.

Fig. 6 demonstrates that substantial shifts in the composition of electricity generation are not the only ones needed; a concomitant further decarbonization of district heat generation and heat supply must occur. Oil, coal, and natural gas must be almost completely phased out by 2040; biomass and waste, geothermal, and electric heat must be ramped up. Heating networks transition not only from fossil fuels but also to heat pumps and electric boilers, adding flexibility to an integrated power and heat system. Moreover, the NETP predicts that by 2050, space heating will come to comprise more than half of total building final energy consumption.

3.2. Energy efficiency in buildings

As briefly mentioned above, the expansion of low-carbon electricity

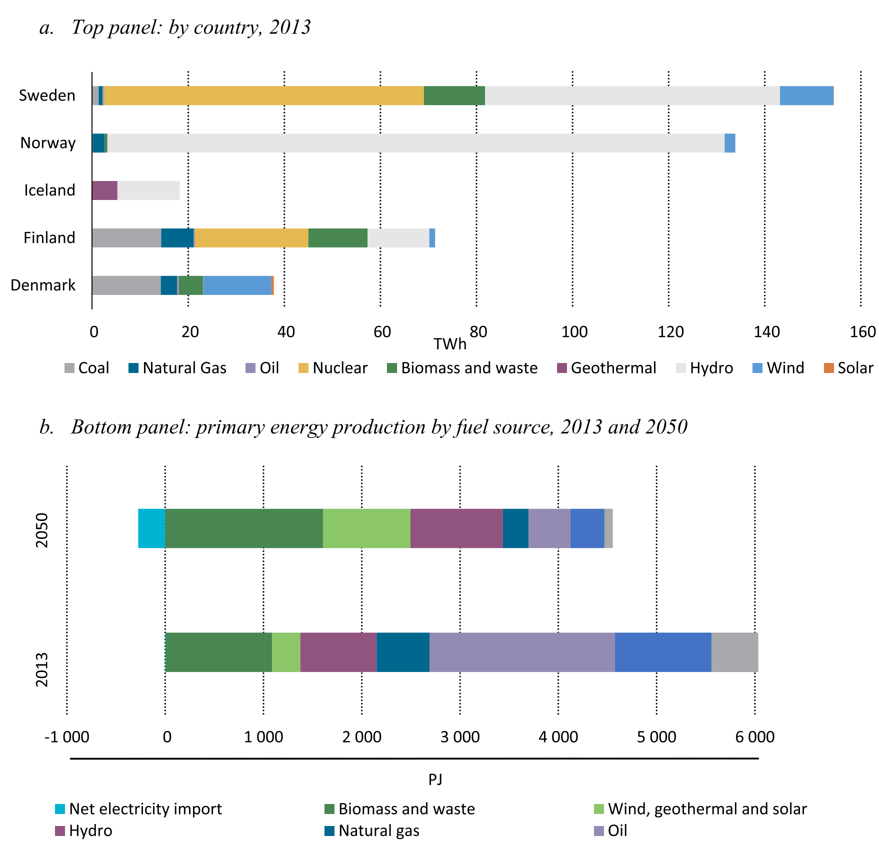


Fig. 4. Electricity generation and primary energy supply in the Nordic countries, 2013–2050.

a. Top panel: Onshore *b. Bottom panel: offshore*

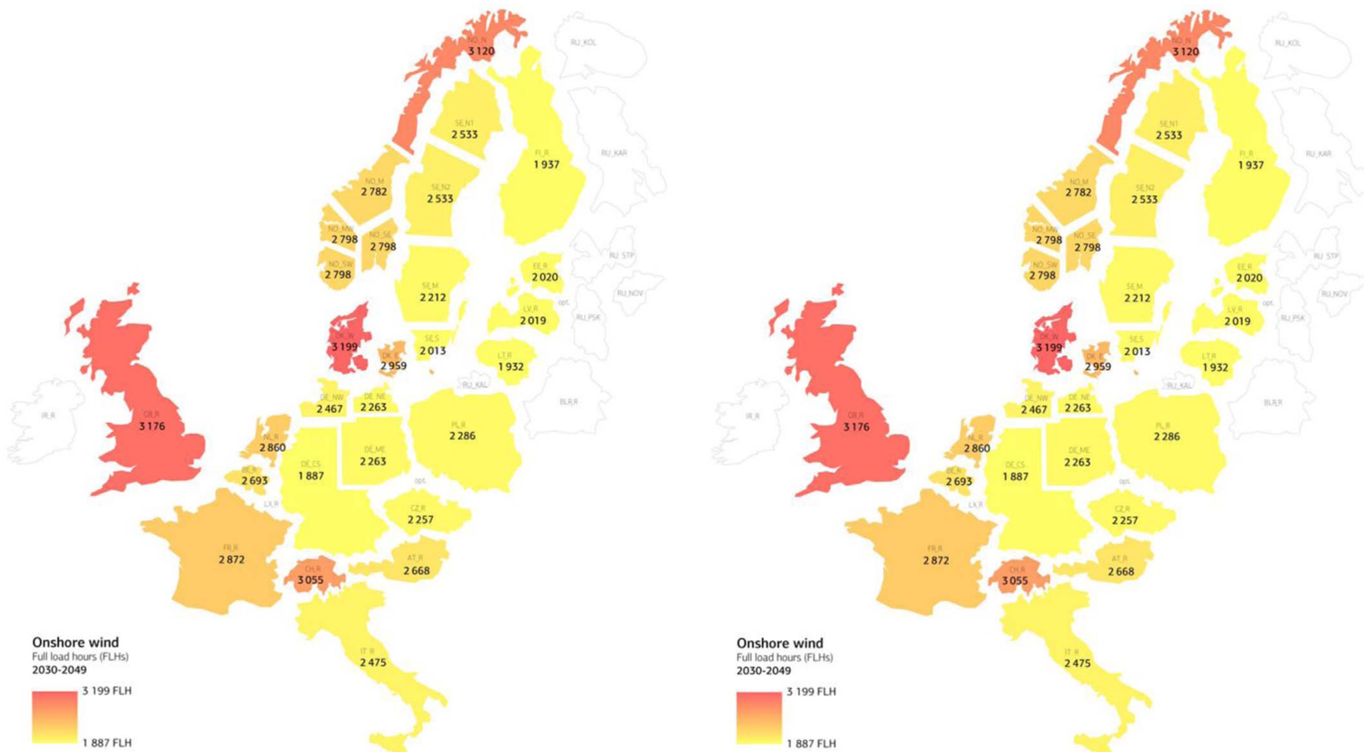
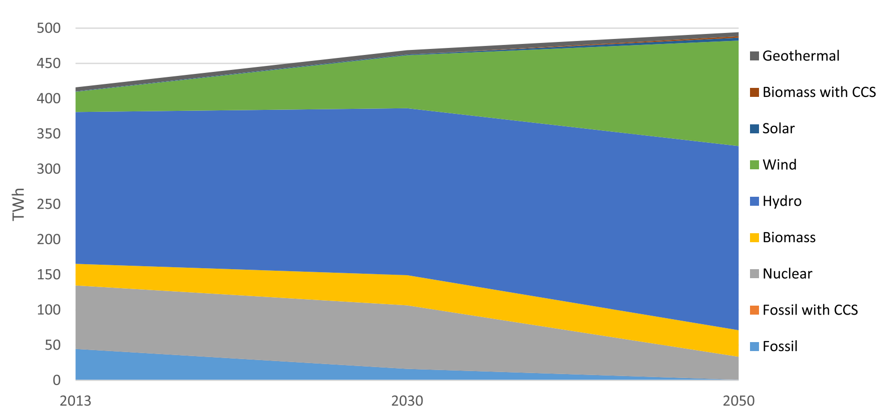


Fig. 5. Full load hours for onshore and offshore wind, 2030–2049.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2016) (Paris: OECD, 2016).

a. Top panel: Electricity generation



b. Bottom panel: heat supply

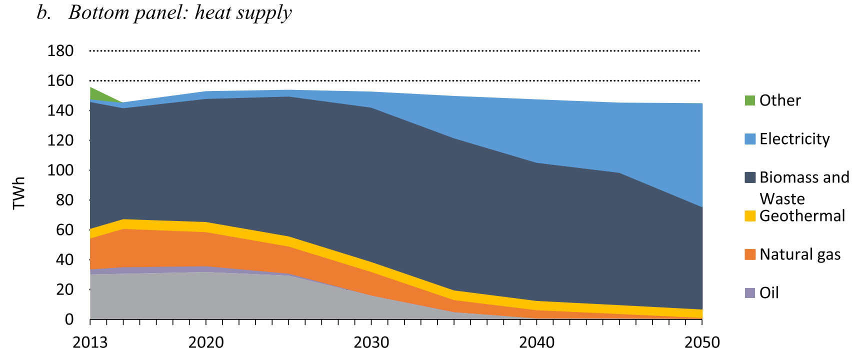


Fig. 6. Nordic electricity generation and district heating supply, 2013–2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2016) (Paris: OECD, 2016). Note: both panels depict the "Carbon Neutral Scenario." TWh = Terrawatt-hours.

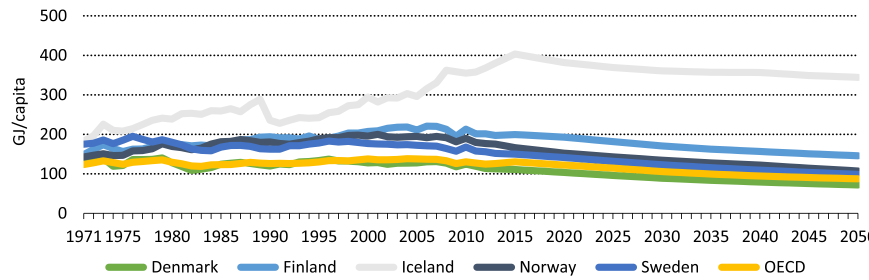
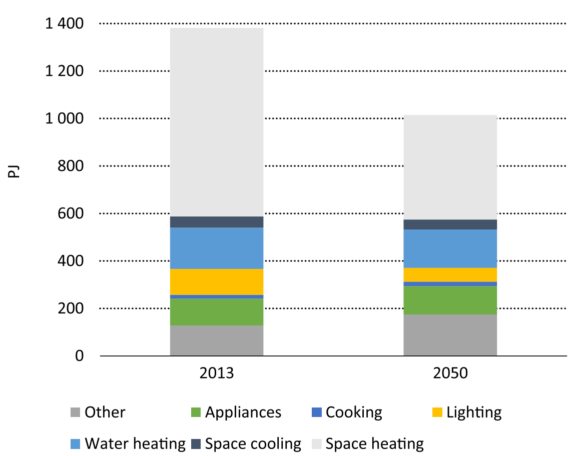


Fig. 7. Per capita energy consumption in the Nordic countries and OECD Average, 1970–2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives 2016 (Paris: OECD, 2016). Note: GJ=Gigajoules. OECD=Organization of Cooperation and Development.

and heat supply networks is only one of four transition pillars. Their growth must be combined with substantive reductions in demand and energy end use in buildings (and industry—discussed in a later section). This challenge is all the more stark given that only Denmark—as Fig. 7 depicts—consumes less energy per capita than the average for countries belonging to the OECD. Iceland, in particular, consumes many times the OECD average and northern countries such as Finland and Norway also consume much more. This is not only because of the harsher, darker winters with higher heating and lighting needs; it is also affected by the fairly low population density outside of the major metropolitan areas of Copenhagen, Helsinki, Oslo, and Stockholm, and the growing energy needs of industry.

a. Top panel: Buildings energy consumption, 2013 and 2050



b. Bottom panel: Energy intensity and emission intensity, 1990 to 2050

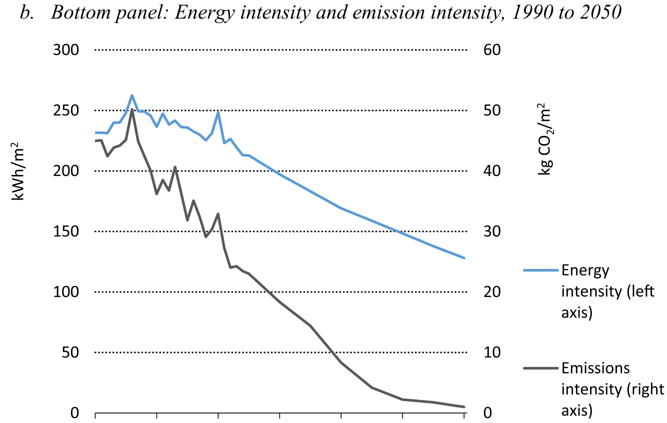


Fig. 8. Nordic buildings energy consumption and energy and emissions intensities, 1990, 2013, and 2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2016) (Paris: OECD, 2016). Note: both panels depict the "Carbon Neutral Scenario." PJ = Petajoules. kWh = kilowatt-hour.

Because of this comparatively high energy use per capita, energy efficiency plays an instrumental role in Nordic decarbonization. Although the Nordic region is already fairly well known for having efficient building stock, demand side management and energy efficiency programs, more gains are needed. A further 35% drop in residential and commercial energy use per square meter must occur between 2010 and 2050. This reflects a monumental investment challenge, and most of it needs targeted in heat: of roughly $170 billion in additional cumulative buildings investments forecast under the NETP compared to the baseline scenario, $155 billion must go to building envelopes and dramatically reducing space heating demand.

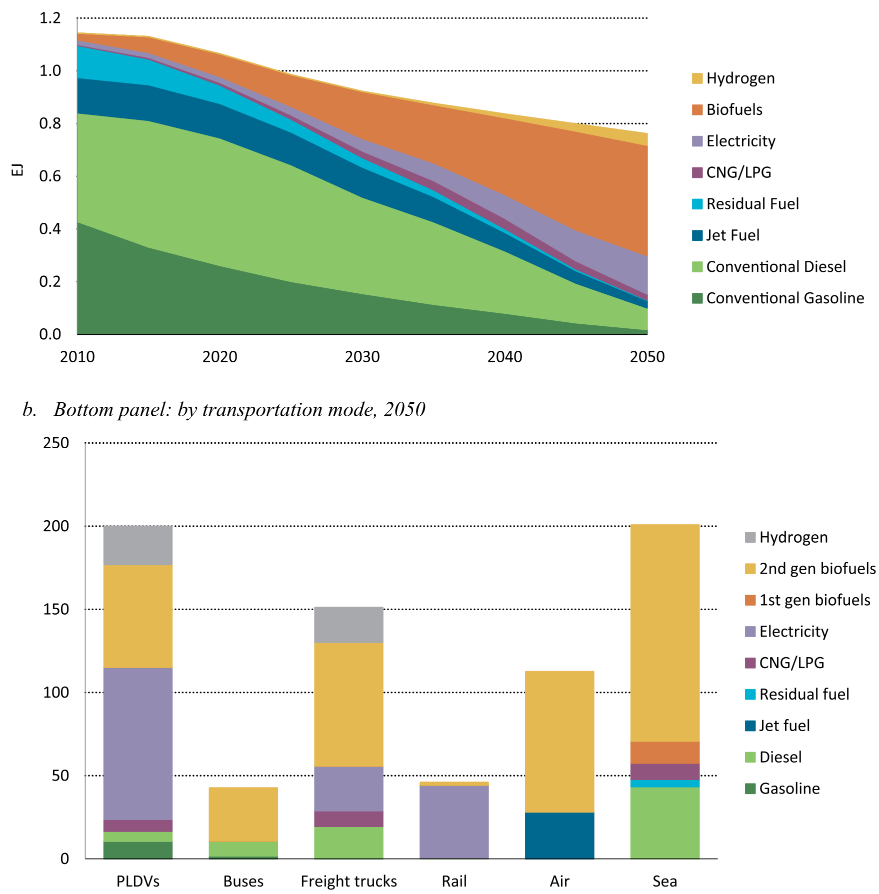
These investments in both energy efficiency efforts (especially building envelopes) and more efficient heat networks are expected to see buildings energy consumption notably decline from 2013 to 2050. As Fig. 8 indicates, total energy consumption in residential and commercial buildings must drop from almost 1400 PJ to 1000 PJ, with corresponding declines in energy intensity as well as carbon intensity. Interestingly, energy demand in Nordic urban buildings is expected to fall to 1990 levels by 2050 even as floor area increases by more than 25%.

There are two implicit assumptions within these projections: integration of efficiency with other policy efforts, and that behavioral change occurs alongside technical improvements. Firstly, the emissions intensity of buildings falls to zero by about 2045 but this is achievable only if proper grid infrastructure investments are made (so Nordic countries can export excess power, offsetting the cost of efficiency upgrades), if bioenergy substitutes fossil fuels for heat, and if new technologies such as low temperature district heating achieve diffusion. Over the longer term, efficiency improvements to buildings come to depend on improved and integrated urban planning and the dissemination of energy management systems that empower consumers. Second, it is these energy management systems that must also encourage behavioral change. Consumers away from urban areas and/or centralized district heating networks must come to adopt heat pumps and solar heating, as well as upgrades to their residential appliances and building stock. For instance, all traditional incandescent and halogen light bulbs must be completely phased out, and energy performance standards must be tightened for appliances and equipment. Consumers in urban areas must also pursue energy efficiency upgrades, especially those that lower peak demand, such as very-high-performance envelopes, including air sealing, insulation, highly insulating windows (e.g. triple-pane, low-emissivity windows) and high- efficiency ventilation. Research from behavioral science and social science suggests that such upgrades and improvements in efficiency will involve significant changes in consumer practices at both the home and workplace (Walker et al., 2014; Sdei et al., 2015; Kastner and Stern, 2015; Sunikka-Blank and Galvin, 2016; Staddon et al., 2016).

3.3. Transport

The transport pillar represents one of the more pernicious chal-

a. Top panel: by fuel source, 2010-2050



b. Bottom panel: by transportation mode, 2050

Fig. 9. Nordic Transportation Modes and Fuel Mixes, 2010–2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2016) (Paris: OECD, 2016). Note: both panels depict the "Carbon Neutral Scenario." EJ = Exajoules. PLDVs = Personal Light Duty Vehicles. CNG = Compressed Natural Gas. LPG = Liquefied Petroleum gas.

lenges for Nordic decarbonization. Transport currently accounts for almost 40% of Nordic carbon dioxide emissions, meaning it therefore holds the potential for greatest emissions reductions. As Fig. 9 indicates, achieving these reductions depends on an almost complete phase out of conventional gasoline and residual fuel and staggering reductions in conventional diesel and jet fuel. Conversely, electricity, biofuel, and hydrogen see considerable growth. As the 2013 version of the report concluded, "the electrification of passenger transport [is one of the] primary building blocks in a low-carbon Nordic transport system." Projections suggest that by 2030, 30% of all new passenger vehicle sales must be full battery electric models, and that number must rise to 90% by 2050. A nearly complete phase out of conventional internal combustion engine vehicles needs to occur by 2050. Underscoring the immensity of the technical challenge is the fact that compared to 2000, transport's total energy usage in 2050 is expected to decrease by more than 20%, yet passenger and freight activity is expected to increase a whopping 70%.

However, as Fig. 9 also reveals, electrification does not work for all transport modes. It expands to account for a majority of personal light duty vehicle consumption and almost all of rail consumption. Electric vehicles become especially attractive in urban areas that have shorter driving distances, more acute air pollution and noise concerns, and better infrastructure for charging. However, the technology simply has not progressed to facilitate a transition to electricity for heavy duty vehicles such as buses, freight trucks, long distance trains, and airplanes. These modes will most likely continue to operate on jet fuel, biofuel, diesel, and gasoline – at least over the next few decades. In 2050, buses are expected to rely on a mix of diesel and biofuel; freight trucks see slightly more penetration of electricity, but that is mostly to offset idling. Air transport and sea depend on biofuel to meet a majority of their transport needs—air because liquid fuel still holds a superior energy density compared to batteries, sea because such fuels can still work in the large one- and two-stroke diesel engines on most sea container ships (Smil, 2010), the idea being that it is most cost effective to substitute the fuel rather than replace the costly engines. This necessitates continued improvement of biofuel, especially since biofuels are expected to meet nearly two-thirds of total final energy demand for transport in 2050.

To reach these targets, transportation fuels must change, but policies (a political tolerance for higher costs) and behavioral patterns must alter as well. For instance, decarbonization of transport through advanced biofuels produced locally will still be more costly than simply participating in conventional biofuel markets. Although further research efforts and technological learning are anticipated to facilitate Nordic biofuel prices declining further, using biomass resources to cover the entire demand for transport would require diverting them from higher value industrial products. So Nordic planners and consumers must tolerate higher costs if they want to source their biofuel sustainably or prioritize domestic production. Moreover, the NETP acknowledges that a three-pronged strategy of avoid, shift, and improve is critical: avoiding transport activity (altering consumer preferences) in addition to shifting to more efficient and less carbon-intensive modes and improving transport fuels and infrastructures. This "avoid" prong depends primarily on influencing driving habits and preferences through additional road tolls, parking fees, restrictions on parking, promoting public transport, and incentivizing cycling and walking.

One very simplified way of viewing transport decarbonization is

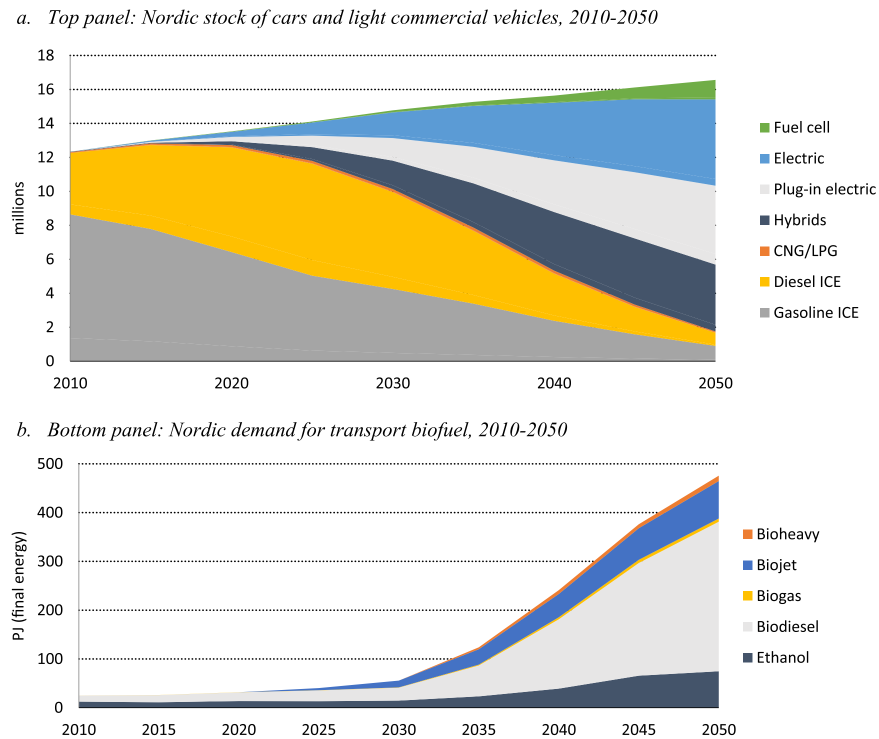


Fig. 10. Nordic vehicle types and demand for transport biofuel, 2010–2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives 2016 (Paris: OECD, 2016). Note: both panels depict the "Carbon Neutral Scenario." PJ = Petajoules. CNG = Compressed Natural Gas. LPG = Liquefied Petroleum gas. ICE = Internal Combustion Engine.

Table 1
Industrial materials production in Nordic countries.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2016) (Paris: OECD, 2016). Note: 2050 column depicts the "Carbon Neutral Scenario." Mt = Million metric tons.

Material production (Mt)	2013	2050	% growth
Crude steel	8.5	9.9	16.5%
Paper and paperboard	25.7	26.7	3.9%
Cement	7.4	8.3	12.2%
Aluminum	6.9	7.0	1.4%
High-value chemicals	2.3	2.5	8.7%
Ammonia	0.4	0.4	0.0%
Methanol	0.8	0.9	12.5%

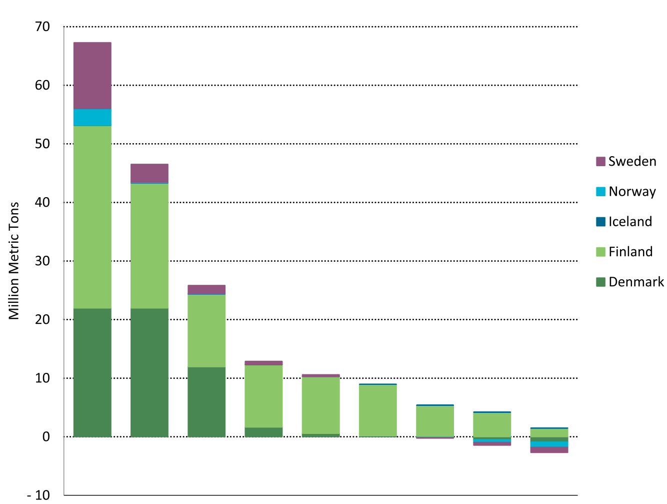


Fig. 11. Nordic Carbon Dioxide Emissions by Country, 2010–2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives 2016 (Paris: OECD, 2016). Note: Figure depicts the "Carbon Neutral Scenario."

that fossil fueled cars are rapidly phased out to accommodate short-distance transport modes, and replaced with a mix of fuel cells, full electric cars, plug in hybrids, and hybrids, whereas biofuel expansion (and imports) are needed to offset long-distance transport modes. These pathways are depicted in Fig. 10.

3.4. Industry and carbon storage

Industry, IEA and Nordic Energy Research put it succinctly, could become a "deal breaker" for meeting climate targets. One fundamental reason is that while fairly radical changes are expected in the other three sectors of electricity/heat, efficiency, and transport, only minor changes are anticipated for industrial structures and the production of materials across the Nordic countries. Moreover, given how intimately industrial production in the Nordic region is tied to jobs and economic development, planners there acknowledge that industrial activity must continue unabated even in a low-carbon society. Despite the perception that the Nordic region relies mostly on a clean, service economy, all Nordic countries except Denmark are highly dependent on energy intensive industrial manufacturing and use more energy per unit of Gross Domestic product than the average across the OECD.

As Table 1 tentatively depicts, given projections connected to population and economic growth, industrial production is actually forecast to increase over the next few decades, with paper in particular maintaining its status as the largest produced commodity across the region, reaching about 26.7 million tons of production a year, followed by steel, cement, and aluminum. Crude steel, cement, and methanol also see double digit increases over the same period. With substantial production therefore in iron and steel, cement, chemicals, and aluminum, many industrial process-related emissions cannot be eliminated through fuel switching or energy efficiency improvements.

Because of this growth in industrial production, carbon capture and storage (CCS) becomes an instrumental part of facilitating economic development while also maintaining decarbonization pathways. As

Fig. 11 indicates, the Nordic countries must start capturing and sinking carbon no later than 2035, and by 2050, they must act as a net sink—storing and sequestering more carbon than they emit. For these reasons, International Energy Agency and Nordic Energy Research (2013) note that CCS "represents the most important option among new technologies for reducing industrial CO_2 emissions after 2030. Currently, great uncertainties exist as to how to deploy CCS, and therefore both CCS demonstrations and closer Nordic collaboration would be needed to overcome the barriers." Indeed, the NETP projects that by 2050, at least 50% of all Nordic cement plants must be fully utilizing CCS along with 30% of iron, steel, and chemical plants. This deployment of CCS is presumed to undergird a necessary 60% reduction in carbon dioxide intensity across industry.

In setting out this industrial trajectory, three additional points merit elaboration. One is that while CCS is the single most important option for industrial decarbonization, it is not the only one expected to be utilized. Energy efficiency measures within industry are expected to reduce final industrial energy consumption by roughly 9% between 2013 and 2050. Process and efficiency improvements such as newer cement kilns, electric arc furnaces for steel and iron production, feedstock and fuel switching for chemicals and petrochemicals, aggressive paper and pulp recycling, and aluminum production through inert anodes processes (among other improvements) are all expected to come online over this period. A second point is that, given the capital intensity and processes involved, Nordic industry has a much slower rate of decarbonization compared to all of the other sectors. A third point is that by 2050, industry comes to account for almost 50% of all remaining Nordic carbon dioxide emissions.

4. What challenges exist?: Contingency, contestation and injustice

To be sure, the Nordic decarbonization pathways articulated above are not simple nor easy in their own right. But, as this section indicates, they must confront at least three interconnected challenges spanning the dimensions of contingency, contestation, and energy justice summarized by Table 2. The Nordic energy transition is sociotechnical (Geels, 2004) in that it must involve altering technological infrastructures alongside political regimes, economic structures, broader global pressures, and even changing consumer preferences. This makes it dependent on a number of diffuse factors, including further development of technology, strong political support, and social acceptance. The idea with listing these barriers is not to be exhaustive—there are likely many more—but more illustrative in the scope and types of challenges faced. What proceeds is admittedly a limited selection of many possible concerns. Nonetheless, the themes of contingency, contestation, and justice are meant to both represent some of the most pressing challenges and also convey new relevant research agendas in the wider energy studies field.

4.1. Technological contingency

The Nordic transition has elements of both historical and future contingency, a dependence on a set of conditions to materialize. Historically, most of the Nordic countries have had strong energy policies in place for many decades, influenced especially by the oil shocks of the 1970s. Denmark in particular has promoted wind electricity, combined heat and power and district heating, and energy efficiency (inclusive of a tax on carbon and revenues funneled back into energy research) since the 1970s and 1980s (Sovacool, 2013). Moreover, the Nordic countries were lucky to have so much hydroelectricity and bioenergy (especially in forests) built out before sustainability and climate change became more salient topics. So in this way, the Nordic transition has been historically contingent on a major global crisis occurring (OPEC embargo) and a degree of fortuitousness in tapping into low-carbon energy resources before climate change became a more significant global topic in the 1990s.

The Nordic transition is contingent on future technical innovation across multiple systems as well. It will depend on technological breakthroughs, but these are not necessarily obvious nor predetermined. In terms of electricity and heat, bioenergy harvesting practices must improve alongside conversion processes and efficiency. Offshore and onshore wind turbines must become more competitive to the point where they supply more than 30% of regional Nordic electricity generation, coupled with advancements in hydroelectricity. Yet offshore wind, apart from higher installation and maintenance costs (reckoned to be greater for floating than fixed turbines), runs the risk of impinging on bird migration routes as was seen in the debate over Horns Rev in Denmark (McCombie and Jefferson, 2016). Solar radiation – direct and for much of the year indirect - in the Nordic countries is, of course, modest (Haukkala, 2015) and the Nordic winter has the least sun precisely when electricity loads peak. Iceland has indeed become a world leader in geothermal energy, but it uses a significant amount of this for aluminum smelting with a consequent increases in sulfur hexafluoride emissions that must be managed (Krater and Rose, 2009).

In the realm of buildings and efficiency, building owners and occupants must come to adopt (and trust) high quality heat pumps and solar heating devices, very-high-performance envelopes, and new techniques such as air sealing, insulation, highly insulating windows and high- efficiency ventilation. However, in some countries such as Sweden, heat pumps would require extensive strengthening of foundations to protect houses from natural radiation, and the rocky substructure of Norway, Sweden and Iceland could make installation difficult (Levesque et al., 1997; Mata et al., 2013).

In the domain of transport, hydrogen fuel cells must enhance their performance but stakeholders remain deeply divided over research pathways (Andreasen and Sovacool, 2015; Enevoldsen et al., 2014). An aggressive expansion of advanced biofuel is necessary, but raises concerns over land use and transport (Fevolden, 2016; Fischer et al.,

Table 2
Sociotechnical challenges facing a Nordic energy transition.

Dimension	Challenge	Description
Technological	Contingency	Reliance on continued technical innovations across renewable electricity systems, heat, efficiency, transport, and (most critically) carbon capture and storage Dependence on continued global efforts to mitigate and respond to climate change, as well as rising fossil fuel prices and a common European Union Energy Policy with more strongly integrated grids
Political	Contestation	Risk of an unstable and unpredictable policy environment Declining rates of social acceptability for decentralized energy systems and electric transmission lines and cables A growing intolerance for carbon and energy targets
Social	Energy Justice and Recognition	Loss of jobs in fossil fuel industries, need for retraining Low levels of energy literacy and understanding about Nordic energy and climate policies Outsourcing and exportation of fossil fuels as well as embodied emissions associated with renewable energy (and others)

2010). Substantial investments in electric vehicles and associated charging infrastructure must occur (Borén et al., 2016; Graabak et al., 2016). Energy storage systems are needed to integrate electricity, heat, buildings, and transport sectors together, but remain only at nascent stages of development (Zafirakis et al., 2016; Beaudin et al., 2010). Most critically, for industry CCS technologies and techniques must not only be demonstrated, but then commercially accepted by a large number of Nordic industrial firms—a large question mark (Anthonsen et al., 2016; Lund and Mathiesen, 2012; Teir et al., 2010; Van Alphen et al., 2009). The Nordic case therefore offers a counter intuitive example of where political goals may not be achieved due to lack of technological innovation, rather than the more common and apparent trend of technological innovation and low-carbon planning frustrated by a lack of political commitment.

A second contingency is more spatial and refers to broader, "landscape" pressures (Geels, 2004) that can alter the desirability or feasibility of decarbonization pathways, especially grid integration with Europe. A current case in point would be the premise within the NETP assumptions that fossil fuel prices continue to rise; yet, as of 2016, oil prices remain below historic trends. Another landscape assumption is that the political environment surrounding the Nordic region remains stable, that is, Germany continues with its *Energiewende* (Zakeri et al., 2016), and other members of the European Union continue to push for a common energy policy that also promotes greater interconnection between the Nordic Power Pool (Nordpool) and European markets. The British exit ("Brexit") from the European Union could erode this assumption about common policy, particularly if more protectionist policies come into play across the continent. Another critical facet here is electric transmission networks and high voltage direct current lines that better link with continental Europe. As Shafiei et al. (2014) warn, "the highly interconnected regional electricity market is the cornerstone of the Nordic energy system, and it can serve as a key enabler for further emission reductions towards 2050." Tenggren et al. (2016) add that "if the Nordic power system is to integrate further with the rest of Europe, there would be a need for more harmonized planning practices not only between the Nordic countries but also with European partners." Moreover, the IEA and Nordic Energy Research (2016) caution that better integration with European electricity markets could also push prices upward, leading to a new regime of high and unstable prices rather than the more traditional low and stable prices that have been a key advantage for Nordic industry.

4.2. Political contestation

The Nordic transition is also contingent on political outcomes and stability. Underpinning its decarbonization pathways are strong policies and policy commitment at not only the regional and national levels, but within municipalities, communes, and local communities. Such pathways depend on the assumption that several Nordic subnational actors will continue to adopt climate and energy targets that are even more aggressive than national goals. They also depend on the stability and predictability of those targets, what one policy analyst referred to as the "three Ls" for effective energy policy: loud, long, and legal: loud in the sense that they offer clear price signals and encourage public involvement; long in that they are consistent and predictable; and legal in that they are backed by strong political support and have penalties for noncompliance (Hamilton, 2009). Change any of these three policy tenets, and you likely alter the policy outcome..

As a sign of how rapidly political goals can change, consider two very recent examples. In August 2015, after a change in political leadership in Denmark, the new Climate Minister Lars Christian Lilleholt announced plans to scale back the country's ambitious carbon reduction goals, arguing that they were too costly for Danish businesses. "It will be very expensive," he remarked, "and will therefore impose extra costs on the business community. This is not what Denmark needs right now" (quoted in Bagger (2015)). Furthermore, the NETP presumes that countries such as Sweden will remain committed to the phase-out of nuclear energy, yet in 2016 the Swedish government announced plans to build new reactors (Milne, 2016). (As a positive sign, a parliamentary commission finished in June 2016 stated that Sweden should aim to be have a 100% renewable energy system by 2045).

A related political obstacle relates to declining rates of social acceptability for some decentralized energy systems such as wind energy as well as electric vehicles, cables and transmission lines. For instance, there is some evidence that Danish perceptions may be changing and that attitudes could start reflecting disaffection with energy and environmental policies. Ladenburg and Dahlgaard (2012) and Ladenburg (2015) have noted that, paradoxically, in some instances repeated exposure to wind turbines can diminish acceptance. Noel and Sovacool (2016) studied the promise of innovative business models for electric mobility and electric vehicles in the Nordic region (though a case study of "Better Place"), and found that despite a stated commitment to green driving, corporate actors had to abandon their projects for lack of consumer interest. Another recent survey in Denmark found that many drivers and commuters remain uninformed or unconcerned about greener transport options (Nielsen et al., 2015). Klitkou et al. (2015) also caution that the relatively slow diffusion of electric vehicles so far across the region has resulted in an underutilization of charging infrastructure, creating a disincentive for further investment. Communities have come to oppose or at least less rigorously support plans for new electric power transmission lines and cables in places such as Norway and Sweden (Aas et al., 2014). Last but not least we have a potentially growing social and political intolerance for carbon and energy targets. Klok et al. (2006) found in an older survey, for instance, that "most participants felt that Denmark had now paid the price of international environmental and social leadership long enough, that Denmark could not continue being superior to the other EU countries (as it was believed Denmark was), and that it was time other countries now took over some of the burden of going in the lead." The nongovernmental group the Council of Environmental Economics, whose members include trade and labor unions, employer's federations, government institutions and nongovernmental organizations, has also consistently proclaimed that strong energy and climate policies such as environmental taxes hurt households and businesses (Quoted in Sovacool and Blyth (2015)).

4.3. Energy justice and recognition

A final type of obstacle relates to energy justice and recognition, defined as achieving a global energy system that fairly disseminates both the benefits and costs of energy services, and one that has representative and impartial energy decision-making (Sovacool and Dworkin, 2014, 2015; Sovacool et al., 2016a). In this context, even though the Nordic low-carbon transition has obvious, tangible benefits, and will create many "winners," it also has at least some "losers" and negative implications from the perspective of energy justice. It may also not recognize explicitly enough vulnerable groups.

At the top of the list are the obvious job losses associated with the displacing of coal, natural gas, and oil, and potentially nuclear power (if the phase-out does indeed occur). Some of these skills and jobs may be transferable to other sectors, such as offshore oil platform engineers instead putting their expertise into offshore wind turbine foundations, but many will not. A related concern is that some of the technologies being pushed by Nordic climate policies, such solar panels or electric vehicles, and especially zero energy homes and more expensive electric appliances or efficiency upgrades, tend not to be utilized by the poor or lower middle class. This could become a pressing equity and affordability concern with how state-of-the-art energy systems are distributed throughout the region—they could amplify already widening gaps between the rich and poor, wealthy and non-wealthy, as well as the power relationship between energy suppliers and users.

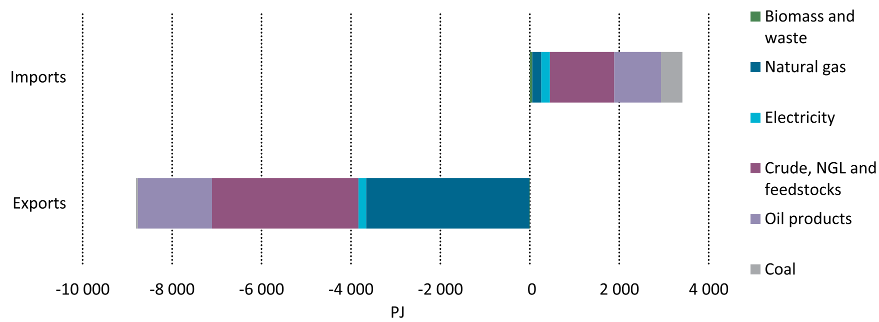


Fig. 12. Nordic exports of primary energy, 2011.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2013) (Paris: OECD, 2013). Note: PJ=Petajoule. NGL=Natural Gas Liquids.

A secondary concern is possible lack of understanding and public input into Nordic climate planning. Sovacool and Blyth (2015) surveyed energy consumers and business leaders in Denmark, and noted that a strong majority of them had widespread lack of public knowledge—an inability to properly assess energy challenges or to grasp energy facts. A possible implication was that the Danish energy transition was only possible to the extent that its people remained uninformed about energy and climate issues.

A final, far more serious justice concern, acknowledged by the NETP in a box on embedded emissions, relates to the exporting or offshoring of Nordic carbon emissions elsewhere. While the Nordic decarbonization pathways above clearly seek to create a fossil-free regional economy, and imply that fossil fuels are socially, economically, and environmentally undesirable, this has not stopped countries such as Norway from continuing to export them, or promoting fossil fuels overseas. Two of Norway's largest enterprises, the Government Pension Fund Global and Statoil, still continue to invest hundreds of millions of dollars in hundreds of different coal and oil companies (Jorde, 2013). This will surely offset the carbon gains made by the Nordic countries themselves, and also place other communities at risk to the externalities across the fossil fuel lifecycle. Indeed, the necessity of Nordic countries meeting their own carbon goals only by exporting fossil fuels elsewhere is noted explicitly in the NETP. As Fig. 12 reveals, the Nordic region is an actual net exporter of primary energy based largely on the trading of oil products, natural gas, and crude feedstocks—exports (by volume) that more than double the amount of domestic production.

This global offshoring of carbon is not limited to fossil fuels. Sovacool et al. (2016b) examined the externalities from manufacturing offshore and onshore wind turbines for use in the Nordic region and found that wind energy has externalities across its construction and manufacturing, ones that both offset (in part) their environmental credentials and also result in significant emissions being outsourced to China and South Korea. Taking into account "environmental profits and losses," the study estimated that China and South Korea accounted for about 80% of embodied emissions and resulting environmental damages across each type of Nordic turbine.

5. What broader lessons emerge?: Conclusions and policy implications

Five conclusions are offered for energy analysts as well as planners and policymakers. First, and positively, is that the Nordic energy transition conclusively demonstrates the cost efficacy and reliability of renewable low-carbon energy systems. The Nordic region already receives a vast share of its electricity generation from low-carbon sources, and Denmark especially generates almost half of its electricity from wind. Fig. 13 shows that a mix of low carbon technologies—energy efficiency, bioenergy, hydroelectricity, wind, solar, and CCS—can expand even more to displace almost 20 million tons of emissions in the power sector by 2030 and more than 90 million tons by 2050. Onshore wind power in particular grows exponentially over this period, expanding fourfold from 24 TWh in 2013 to TWh in 2050, and offshore wind grows eightfold to 40 TWh. Nuclear generation falls by two-thirds with all remaining reactors residing only in Finland. From a regional scale, nuclear power falls from 22% of Nordic electricity generation in 2013 to 6% in 2050.

The NETP also suggests that if a carbon-neutral system is achieved, it will likely cost less transitioning to a more distributed, integrated, and flexible system than one dependent on centralized nuclear and thermoelectric power plants. As Table 3 indicates, the total estimated cost of the Nordic energy transition is roughly $357 billion, totaling less than 1% of cumulative GDP over the period—and almost all of these costs will be offset by fuel savings. Indeed, the IEA and Nordic Energy (2016: 25–26) estimate that the external costs associated with the health impacts of air pollution alone in the Nordic countries (about $9 to $14 billion annually) are roughly equal to the additional investment needed to achieve a carbon neutral scenario. Put another way, by displacing pollution the Nordic energy transition pays for itself.

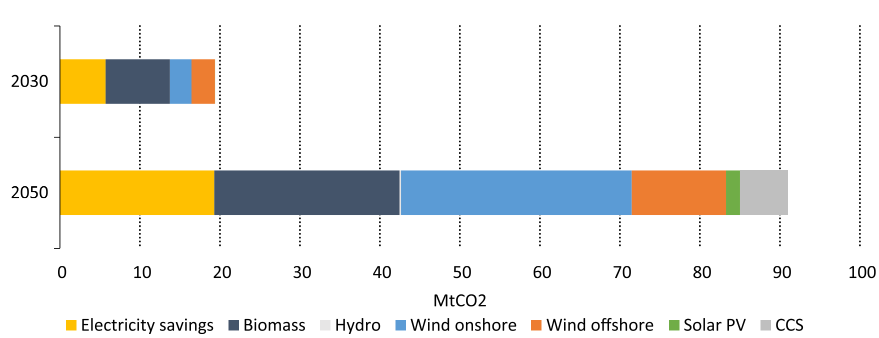


Fig. 13. Low-Carbon Electricity Systems in the Nordic Region, 2030 and 2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2016) (Paris: OECD, 2016). Note: MT=Million metric tons. CO2= Carbon Dioxide. PV=Photovoltaic. CCS=Carbon Capture and Storage.

Table 3
Cumulative Nordic Investments for Decarbonization by Sector, 2016–2050.
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives (2016) (Paris: OECD, 2016). Assumes the Carbon Neutral Scenario.

Sector	$ (USD Million)
Energy-related investments in buildings	326
Industry	103
Transport: vehicles	1674
Transport: infrastructure	1121
Power: generation	197
Power: infrastructure	151
Total	3572

Second, trade and interconnection with Europe are instrumental to the Nordic countries reaching their carbon and energy targets. If average generation costs in continental Europe stay higher than in the Nordic region, then it becomes a major exporter of 53 TW h of electricity in 2050. As Fig. 14 illustrates, Nordic electricity trade must expand considerably—underscoring the need for paralleled, coordinated grid development and interconnections with Great Britain, the Netherlands, Germany, Poland, Lithuania, Latvia, and Estonia. Additionally, by 2050, 16% of total Nordic biomass demand across all sectors (especially transport, where biofuel needs to substitute for oil) will need to be met by imports, including for refueling at Nordic ports. International cooperation is also needed through international pricing of carbon and common principles with Europe concerning energy performance auditing mechanisms. This amplifies the extra-territorial dimensions of the Nordic transition.

Third, while driven significantly by national policies and regional governance principles, it is actually subnational actors that serve to drive most of the four decarbonization pathways across electricity and heat, efficiency, transport, and industry. Cities and municipalities take the lead as actors, especially given that urbanization rates across the Nordic region are expected to occur at double the rate of previous decades. It is cities that will need to invest in new buildings, sponsor retrofits, erect electric vehicle charging infrastructure, and optimize heat networks. Nordic capital cities are already roughly 30% more efficient than the average for buildings and 40% more efficient for transport, due to economies of scale, infrastructural availability, and greater population density. It is also cities that are uniquely advanced and progressive in terms of energy systems integration, with well-established heating and cooling networks and many within close proximity of medium sized power plants.

Fourth, the Nordic case emphasizes that energy transitions take generations. Even for a group of relatively wealthy, small, and committed countries, the transition will take at least three to four more *decades*. Its success rests upon a number of compelling technological contingences or breakthroughs, each of them will require time—to name a few, a continued phase out of nuclear power; a rapid ramping up of onshore and offshore wind energy; a spectacular diffusion of electric vehicles; a massive increase in bioenergy produc-

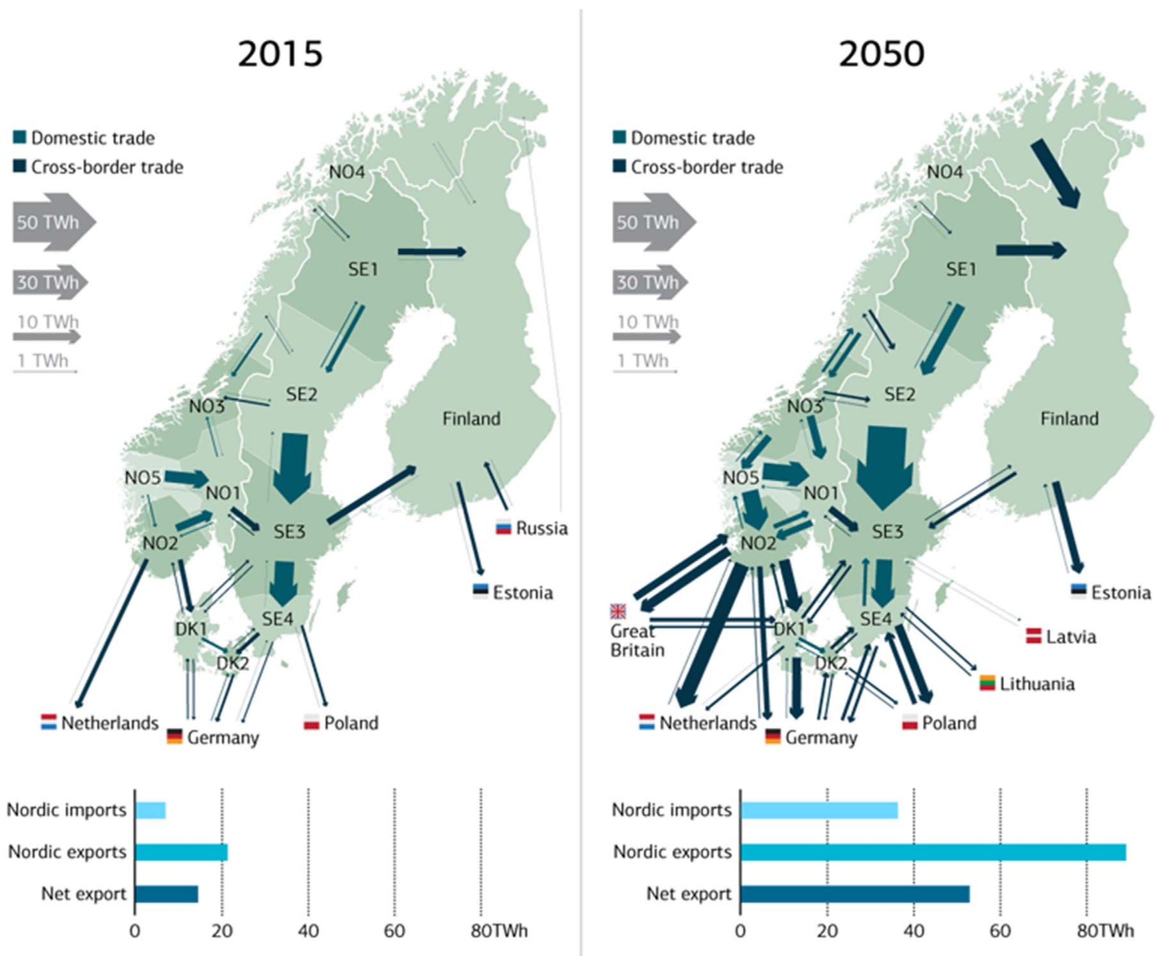


Fig. 14. Nordic Electricity Trade in 2015 (left) and 2050 (right).
Source: Modified from International Energy Agency and Nordic Energy Research, Nordic Energy Technology Perspectives 2016 (Paris: OECD, 2016). Assumes the Carbon Neutral Scenario.

tion; and the commercialization of industrial scale carbon capture and storage. On top of this, households and consumers must learn to adopt better energy management systems and industrial planners must come to adopt newer cement kilns, electric arc furnaces, and feedstock switching for chemicals, petrochemicals, and paper and pulping.

Fifth, and lastly, however, is that the Nordic transition, for all of its promise, remains contingent, contested, and potentially unjust. As one constraining factor, there are elements of the Nordic transition unique to its own sociotechnical environment—countries endowed with plentiful fossil fuels that they can export to generate revenue they funnel back into domestic decarbonization, coupled with a history of strong energy and climate planning and high fuel and electricity prices. The Nordic blueprint, moreover, will most certainly *not* be adopted globally, especially in places like the United States with its poisonous partisan politics (Hess et al., 2016), China and its scramble for energy resources of all shapes and sizes (Green and Kryman, 2014), and India with its focus on expanding access to energy regardless of its source (Palit et al., 2013). Then we have some very real justice and recognition concerns including those set to lose their jobs as fossil fuels are displaced, a lack of understanding among some citizens about energy and climate topics, and the outsourcing of embodied carbon emissions overseas. In sum, even the history and the future of Nordic decarbonization—perhaps the exemplar for the world—reminds us that energy transitions are more technologically contingent, contextually specific, and politically contested processes than perhaps we would like to believe.

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